

WORK STATEMENT

TECHNICAL TASK LIST

| Task # | CPR | Task Name |
|--------|-----|--|
| 1 | | Administration |
| 2 | | Technical Tasks |
| 2.1 | | Set up Wet Lab and Outdoor Tanks |
| 2.2 | | OMEGA Integrity Tests |
| 2.3 | X | Filling, Dewatering, Harvesting Test |
| 2.4 | X | Algae Growth and Lipid Extraction |
| 2.5 | | Ocean Deployment and Scale-up |
| 3.1 | | Technology Transfer and Commercialization Activities |

KEY NAME LIST

| Task # | Key Personnel | Key Subcontractor(s) | Key Partner(s) |
|--------|---|----------------------|--|
| 1.1 | K. Phillips, Marilyn Murakami J. Trent | | |
| 1.2 | S. Gormly, J. Trent | | |
| 1.3 | R. Baertsch-J. Trent | | |
| 1.5 | R. Baertsch, P. Buckwalter, T. Embaye, S. Gormly, T. Liggett, K. Phillips, J. Trent | | |
| 1.6 | S. Gormly, K. Phillips, E. Thompson J. Trent | | Santa Cruz, San Jose, STEPS Institute |
| 2.1 | P. Buckwalter, T. Embaye, S. Gormly, T. Liggett, J. Trent | | MBARI |
| 2.2 | P. Buckwalter, T. Embaye, S. Gormly, T. Liggett, K. Phillips, J. Trent | | MBARI, Santa Cruz, San Jose, STEPS Institute |
| 2.3 | R. Baertsch, P. Buckwalter, T. Embaye, S. Gormly, T. Liggett, K. Phillips, J. Trent | | MBARI, Santa Cruz, San Jose, STEPS Institute |
| 2.4 | R. Baertsch, P. Buckwalter, T. Embaye, K. Phillips, J. Trent | | MBARI, Santa Cruz, San Jose, STEPS Institute |
| 2.5 | R. Baertsch, P. Buckwalter, T. Embaye, S. Gormly, K. Phillips, J. Trent | | MBARI, Santa Cruz, San Jose, STEPS Institute |
| 3.1 | K. Phillips, J. Trent | | NASA Technology Transfer Office |

GLOSSARY

| Term/ Acronym | Definition |
|------------------|--|
| OMEGA | Offshore Membrane Enclosures for Growing Algae |
| CPR | Critical Project Review |
| FO | Forward Osmosis |
| PAC | Project Advisory Committee |
| PIER | Public Interest Energy Research |
| MBARI | Monterey Bay Aquarium Research Institution |
| RD&D | Research, Development and Demonstration |
| STEPS | Science, Technology, Engineering, Policy and Society |

Problem Statement:

Algae is the best-known source of oil for biofuels, producing >2000 gallons/acre/year, compared to 50 gal/acre/yr for soybeans or 600 gal/acre/yr for palm oil (Benemann, 2007). Although algae are by far the best-known source of oil, current algae cultivation methods on land (open ponds and closed bioreactors) have fundamental problems that prevent them from producing enough algae to meet California's transportation fuel needs practically or economically.

NASA Ames plans to revolutionize algae production by cultivating algae offshore in flexible plastic enclosures called OMEGAs, which not only addresses the most significant problems cultivating algae on land, but also simultaneously addresses growing environmental concerns about the oceans. By growing algae in OMEGAs using municipal wastewater, the problems of capital costs, evaporation and water use, weed species, temperature control, and energy-intensive mixing can be addressed. The algae in the OMEGAs remove nutrients from the wastewater and the FO membranes used in the OMEGA system to dewater the algae, and release only tertiary-treated (clean) water into the ocean. Thus the OMEGA system contributes to the remediation of dead-zones in coastal regions, which are caused by excess nutrients from wastewater. Furthermore, the nutrients in the wastewater, which are currently being lost at sea, will be recovered with the algae, and in addition to providing biofuels, the algae can be used for fertilizer as well as other valued products. Finally, the algae will take up carbon dioxide from the atmosphere as they grow and this carbon can be sequestered by transforming the algal into biochar. Biochar functions as a soil amendment at the same time it keeps carbon out of the atmosphere. Algae OMEGA is therefore a triple-pay-back system: 1) it provides a sustainable local source of liquid fuel in addition to fertilizer, and other valued products, 2) it functions as a tertiary-treatment facility for municipal wastewater, and 3) it provides a basis for sequestering CO₂ from the atmosphere by the formation of biochar. This is accomplished without competing for agricultural land and freshwater.

Goals of the Agreement:

The primary goal of this project is to demonstrate that OMEGA is a technologically and economically viable system for growing algae for biofuels, while providing other valued products and services. This demonstration will involve four technical milestones that include laboratory, field, and policy-related tasks and objectives. At the end of this project OMEGA will be ready for further scale-up and potential commercialization.

Objectives of the Agreement:

The Technical objectives of this Agreement are to demonstrate the feasibility of using OMEGA to meet the challenges of producing a constant and economically viable supply of algal-based feedstock for biofuels, while simultaneously improving conditions in our coastal oceans in the vicinity of municipal wastewater outfalls.

This project's goals and milestones are directly measurable as kilograms of algal biomass per area per time, lipid production, volume of wastewater processed, and amount of biochar produced.

Technical objectives:

- Demonstrate long-term performance of FO membranes for dewatering algal biomass, concentrating nutrients, and tertiary-treatment of wastewater.
- Demonstrate that an OMEGA design can withstand up to 6 months of deployment without material (leakage, breakage) or functional (transparency, mixing, membrane activities) failures.
- Determine the growth rates and yield of algae in OMEGAs under lab and field conditions using secondary effluent and optimized media for oil production.

Environmental Objectives:

- Demonstrate in tanks how the presence of OMEGAs influences the surrounding phytoplankton community with and without secondary wastewater added.
- Determine in tanks the effect of a simulated OMEGA breakup with secondary wastewater and freshwater algal biomass released.
- Observe in field deployments if seabirds or marine mammals are influenced by the presence of OMEGAs.
- Establish what policy and permitting hurdles must be overcome to implement OMEGAs on a large scale off the coast of California.

Economic Objectives:

- Determine a performance-based likely capital cost range for OMEGA bioreactors.

- Develop probable life-cycle cost models for OMEGAs based on the stability of designs developed and the replacement costs of materials.
- Develop a probable return on investment (ROI) cost model for deployment of algal bioreactors using payback models that include biofuels, fertilizer, and nutraceutical production, as well as wastewater treatment services, and carbon sequestration.

Product Guidelines:

For complete product guidelines, refer to Section 5 in the Terms and Conditions.

TASK 1 ADMINISTRATION

Task 1.1 Attend Kick-off Meeting:

The goal of this task is to establish the lines of communication and procedures for implementing this Agreement.

The Recipient shall:

- Attend a “Kick-Off” meeting with the Commission Project Manager, the Grants Officer, and a representative of the Accounting Office. The Recipient shall bring its Project Manager, Agreement Administrator, Accounting Officer, and others designated by the Commission Project Manager to this meeting. The administrative and technical aspects of this Agreement will be discussed at the meeting. Prior to the kick-off meeting, the Commission Project Manager will provide an agenda to all potential meeting participants.

The administrative portion of the meeting shall include, but not be limited to, the following:

- Discussion of the terms and conditions of the Agreement
- Discussion of Critical Project Review (Task 1.2)
- Match fund documentation (Task 1.6)
- Permit documentation (Task 1.7)

The technical portion of the meeting shall include, but not be limited to, the following:

- The Commission Project Manager’s expectations for accomplishing tasks described in the Scope of Work
- An updated Schedule of Products
- Discussion of Progress Reports (Task 1.4)
- Discussion of Technical Products (Product Guidelines located in Section 5 of the Terms and Conditions)
- Discussion of the Final Report (Task 1.5)

The Commission Project Manager shall:

- Designate the date and location of this meeting.

Recipient Products:

- Updated Schedule of Products
- Updated List of Match Funds
- Updated List of Permits

Commission Project Manager Product:

- Kick-Off Meeting Agenda

Task 1.2 Critical Project Review (CPR) Meetings:

The goal of this task is to determine if the project should continue to receive Energy Commission funding to complete this Agreement and to identify any needed modifications to the tasks, products, schedule or budget.

CPRs provide the opportunity for frank discussions between the Energy Commission and the Recipient. CPRs generally take place at key, predetermined points in the Agreement, as determined by the Commission Project Manager and as shown in the Technical Task List above. However, the Commission Project Manager may schedule additional CPRs as necessary, and any additional costs will be borne by the Recipient.

Participants include the Commission Project Manager and the Recipient and may include the Commission Grants Officer, the Public Interest Energy Research (PIER) Program Team Lead, other Energy Commission staff and Management as well as other individuals selected by the Commission Project Manager to provide support to the Energy Commission.

The Commission Project Manager shall:

- Determine the location, date, and time of each CPR meeting with the Recipient. These meetings generally take place at the Energy Commission, but they may take place at another location.
- Send the Recipient the agenda and a list of expected participants in advance of each CPR. If applicable, the agenda shall include a discussion on both match funding and permits.
- Conduct and make a record of each CPR meeting. One of the outcomes of this meeting will be a schedule for providing the written determination described below.
- Determine whether to continue the project, and if continuing, whether or not modifications are needed to the tasks, schedule, products, and/or budget for the remainder of the Agreement. Modifications to the Agreement may require a formal amendment (please see the Terms and Conditions). If the Commission Project Manager concludes that satisfactory progress is not being made, this conclusion will be referred to the Energy Commission's

Research, Development and Demonstration (RD&D) Policy Committee for its concurrence.

- Provide the Recipient with a written determination in accordance with the schedule. The written response may include a requirement for the Recipient to revise one or more product(s) that were included in the CPR.

The Recipient shall:

- Prepare a CPR Report for each CPR that discusses the progress of the Agreement toward achieving its goals and objectives. This report shall include recommendations and conclusions regarding continued work of the projects. This report shall be submitted along with any other products identified in this scope of work. The Recipient shall submit these documents to the Commission Project Manager and any other designated reviewers at least 15 working days in advance of each CPR meeting.
- Present the required information at each CPR meeting and participate in a discussion about the Agreement.

Commission Project Manager Products:

- Agenda and a list of expected participants
- Schedule for written determination
- Written determination

Recipient Products:

- CPR Report(s)

Task 1.3 Final Meeting:

The goal of this task is to close out this Agreement.

The Recipient shall:

- Meet with Energy Commission staff to present the findings, conclusions, and recommendations. The final meeting must be completed during the closeout of this Agreement.

This meeting will be attended by, at a minimum, the Recipient, the Commission Grants Office Officer, and the Commission Project Manager. The technical and administrative aspects of Agreement closeout will be discussed at the meeting, which may be two separate meetings at the discretion of the Commission Project Manager.

The technical portion of the meeting shall present an assessment of the degree to which project and task goals and objectives were achieved, findings, conclusions, recommended next steps (if any)

for the Agreement, and recommendations for improvements. The Commission Project Manager will determine the appropriate meeting participants.

The administrative portion of the meeting shall be a discussion with the Commission Project Manager and the Grants Officer about the following Agreement closeout items:

- What to do with any equipment purchased with Energy Commission funds (Options).
- Energy Commission's request for specific "generated" data (not already provided in Agreement products).
- Need to document Recipient's disclosure of "subject inventions" developed under the Agreement.
- "Surviving" Agreement provisions, such as repayment provisions and confidential Products.
- Final invoicing and release of retention.
- Prepare a schedule for completing the closeout activities for this Agreement.

Products:

- Written documentation of meeting agreements
- Schedule for completing closeout activities

Task 1.4 Monthly Progress Reports:

The goal of this task is to periodically verify that satisfactory and continued progress is made towards achieving the research objectives of this Agreement on time and within budget.

The objectives of this task are to summarize activities performed during the reporting period, to identify activities planned for the next reporting period, to identify issues that may affect performance and expenditures, and to form the basis for determining whether invoices are consistent with work performed.

The Recipient shall:

- Prepare a Monthly Progress Report, which summarizes all Agreement activities conducted by the Recipient for the reporting period, including an assessment of the ability to complete the Agreement within the current budget and any anticipated cost overruns. Each progress report is due to the Commission Project Manager within 10 working days of the end of the reporting period. The recommended specifications for each progress report are contained in the terms and conditions of this Agreement.

Products:

- Monthly Progress Reports

Task 1.5 Final Report:

The goal of the Final Report is to assess the project's success in achieving its goals and objectives, advancing science and technology, and providing energy-related and other benefits to California.

The objectives of the Final Report are to clearly and completely describe the project's purpose, approach, activities performed, results, and advancements in science and technology; to present a public assessment of the success of the project as measured by the degree to which goals and objectives were achieved; to make insightful observations based on results obtained; to draw conclusions; and to make recommendations for further RD&D projects and improvements to the PIER project management processes.

The final report shall be a public document. If the Recipient has obtained confidential status from the Energy Commission and will be preparing a confidential version of the Final Report as well, the Recipient shall perform the following activities for both the public and confidential versions of the Final Report.

The Recipient shall:

- Prepare an Outline of the Final Report.
- Prepare a Final Report following the approved outline and the latest version of the PIER Final Report guidelines published on the Energy Commission's website at <http://www.energy.ca.gov/contracts/pier/contractors/index.html> at the time the Recipient begins performing this task, unless otherwise instructed in writing by the Commission Project Manager. Instead of the timeframe listed in the Product Guidelines located in Section 5 of the Terms and Conditions, the Commission Project Manager shall provide written comments on the Draft Final Report within fifteen (15) working days of receipt. The Final Report must be completed on or before the end of the Agreement Term.
- Submit one bound copy of the Final Report with the final invoice.

Products:

- Draft Outline of the Final Report
- Final Outline of the Final Report
- Draft Final Report
- Final Report

Task 1.6 Identify and Obtain Matching Funds:

While no significant matching funds have been identified at this time, it will be an ongoing goal to find match funds for this Agreement and if obtained and applied to this Agreement during the term of this Agreement the costs to obtain and document matching fund commitments will not be reimbursed through this

Agreement. Match funds will be identified in writing and the associated commitments obtained before any costs will be reimbursed.

The Recipient shall:

- Prepare a letter documenting the match funding committed to this Agreement and submit it to the Commission Project Manager at least 2 working days prior to the kick-off meeting. If no match funds were part of the proposal that led to the Energy Commission awarding this Agreement and none have been identified at the time this Agreement starts, then state such in the letter. If match funds were a part of the proposal that led to the Energy Commission awarding this Agreement, then provide in the letter a list of the match funds that identifies the:
 - Amount of each cash match fund, its source, including a contact name, address and telephone number and the task(s) to which the match funds will be applied.
 - Amount of each in-kind contribution, a description, documented market or book value, and its source, including a contact name, address and telephone number and the task(s) to which the match funds will be applied. If the in-kind contribution is equipment or other tangible or real property, the Recipient shall identify its owner and provide a contact name, address and telephone number, and the address where the property is located.
- Provide a copy of the letter of commitment from an authorized representative of each source of cash match funding or in-kind contributions that these funds or contributions have been secured.
- Discuss match funds and the implications to the Agreement if they are reduced or not obtained as committed, at the kick-off meeting. If applicable, match funds will be included as a line item in the progress reports and will be a topic at CPR meetings.
- Provide the appropriate information to the Commission Project Manager if during the course of the Agreement additional match funds are received.
- Notify the Commission Project Manager within 10 working days if during the course of the Agreement existing match funds are reduced. Reduction in match funds must be approved through a formal amendment to the Agreement and may trigger an additional CPR.

Products:

- A letter regarding match funds or stating that no match funds are provided
- Copy(ies) of each match fund commitment letter(s) (if applicable)
- Letter(s) for new match funds (if applicable)
- Letter that match funds were reduced (if applicable)

Task 1.7 Identify and Obtain Required Permits:

The goal of this task is to obtain all permits required for work completed under this Agreement in advance of the date they are needed to keep the Agreement schedule on track.

Permit costs and the expenses associated with obtaining permits are not reimbursable under this Agreement. Although the PIER budget for this task will be zero dollars, the Recipient shall budget match funds for any expected expenditures associated with obtaining permits. Permits must be identified in writing and obtained before the Recipient can make any expenditures for which a permit is required.

The Recipient shall:

- Prepare a letter documenting the permits required to conduct this Agreement and submit it to the Commission Project Manager at least 2 working days prior to the kick-off meeting. If there are no permits required at the start of this Agreement, then state such in the letter. If it is known at the beginning of the Agreement that permits will be required during the course of the Agreement, provide in the letter:
 - A list of the permits that identifies the:
 - Type of permit.
 - Name, address and telephone number of the permitting jurisdictions or lead agencies.
 - The schedule the Recipient will follow in applying for and obtaining these permits.
- Discuss the list of permits and the schedule for obtaining them at the kick-off meeting and develop a timetable for submitting the updated list, schedule and the copies of the permits. The implications to the Agreement if the permits are not obtained in a timely fashion or are denied will also be discussed. If applicable, permits will be included as a line item in the Progress Reports and will be a topic at CPR meetings.
- If during the course of the Agreement additional permits become necessary, provide the appropriate information on each permit and an updated schedule to the Commission Project Manager.
- As permits are obtained, send a copy of each approved permit to the Commission Project Manager.
- If during the course of the Agreement permits are not obtained on time or are denied, notify the Commission Project Manager within 10 days. Either of these events may trigger an additional CPR.

Products:

- Letter documenting the permits or stating that no permits are required
- A copy of each approved permit (if applicable)

- Updated list of permits as they change during the term of the Agreement (if applicable)
- Updated schedule for acquiring permits as changes occur during the term of the Agreement (if applicable)

TECHNICAL TASKS

Task 2.1 Set Up Wet Lab and Outdoor Tanks

The goal of this task is to prepare the necessary facilities in which to design, build, and test OMEGAs under laboratory, simulated, and actual field conditions

The Recipient shall:

- Obtain necessary equipment and supplies for constructing OMEGAs and growing algae.
- Establish laboratory testing facilities and conditions for working with wastewater.
- Identify field sites for OMEGA testing and obtain needed permissions and permits.
- Obtain access to appropriate municipal wastewater source.
- Purchase materials for constructing moorings.

Products:

- Letter confirming that test facilities have been established
- Protocol for safety conducting experiments with municipal wastewater
- Interim Progress Report addressing:
 - Procurement of equipment and supplies
 - Establishment of laboratory testing facilities and wastewater working conditions
 - Status of OMEGA testing site procurement, permission and permitting efforts
 - Status of appropriate municipal wastewater sourcing

Task 2.2 OMEGA Integrity Tests:

The goal of this task is to optimize the design of OMEGAs to determine criteria for their optimal performance and durability at sea.

The Recipient shall:

- Prepare an appropriate Test Plan.
- Build and test various designs of OMEGAs in different sizes.
- Determine strength of OMEGA materials (plastics, FO membranes, gas-permeable membranes, attachments) in lab and larger systems in ponds or tanks.

- Fabricate all necessary mooring and support structures and test OMEGAs on these structures in tanks, ponds, and at sea.
- Test OMEGAs as an inter-connected array at selected demo site.
- Test OMEGA's strength and durability under simulated and actual ocean conditions.

Products:

- Test Plan
- Multiple OMEGA designs at different scales
- Criteria for building OMEGAs that will withstand conditions at sea
- Functional moorings in approved locations
- Interim Progress Report addressing:
 - Preparation of an appropriate Test Plan
 - Building and testing of various designs of OMEGA's in different sizes
 - Determination of strength of OMEGA material (plastics, FO membranes, gas-permeable membranes, attachments) in lab and larger systems in ponds or tanks
 - Fabrication of all necessary mooring and support structures and test OMEGAs on these structures in tanks, ponds, and at sea
 - Testing of OMEGAs as an inter-connected array at selected demo site
 - Testing of OMEGAs strength and durability under simulated and actual ocean conditions

Task 2.3 Filling, Dewatering, and Harvesting Test

The goal of this task is to develop the “plumbing” required to fill, dewater, and harvest the OMEGAs, i.e. the kind of tubing and connections that could be used for the transfer of wastewater to the OMEGA and the removal of cultivated algae for filling and harvesting, respectively.

The Recipient shall:

- Prepare an appropriate Test Plan.
- Build prototype filling and harvesting stations to establish plausible protocols
- Test various connections to facilitate filling and harvesting without leakage.
- Determine failure modes for filling-harvesting tubing and connectors.
- Monitor dewatering rates of FO membranes with repeated uses.
- Optimize CO₂ infusion methods using gas-permeable membranes.
- Test all systems in lab, tanks, ponds, and at sea.
- Participate in Critical Project Review meeting.

Products:

- Test Plan
- Critical Design Review Meeting Report
- Interim Progress Report addressing:
 - Information on gas-permeable membranes and criteria for CO₂ infusion
 - Building of prototype filling and harvesting stations to establish plausible protocols
 - Testing of various connections to facilitate filling and harvesting without leakage
 - Determination of failure modes for filling-harvesting tubing and connectors
 - Monitoring of dewatering rates of FO membranes with repeated uses
 - Optimization of CO₂ infusion methods using gas-permeable membranes
 - Testing of all systems in lab, tanks, ponds, and at sea

Task 2.4 Algae Growth and Lipid Extraction

The goal of this task is to document the growth rates, biomass yields, and lipid production of different species of oil-producing algae in OMEGAs, with targets of: (a) a growth cycle of 14 days; (b) biomass yield of >4 grams algae/liter; and (c) >22% dry weight lipid production.

The Recipient shall:

- Prepare Test Plan.
- Determine and optimize algal growth conditions, including media, light levels, mixing, and competition with weed species.
- Determine and optimize growth vs. lipid production conditions.
- Test and optimize lipid extraction and recovery protocols.
- Test samples of algal lipids as a fuel feedstock (use commercial biodiesel facility).
- Based on productivity, create economic models for OMEGAs that include biofuels, fertilizers, other products as well as wastewater services and carbon sequestration.
- Participate in Critical Design Review Meeting.

Products:

- Test Plan
- Cost model based on biomass, products, and services
- Critical design review meeting report
- Interim Progress report addressing:
 - Determination and optimization of algal growth conditions, including media, light levels, mixing, and competition with weed species

- Determination and optimization of growth vs. lipid production conditions
- Testing and optimization of lipid extractions and recovery protocol
- Testing of samples of algal lipids as a fuel feedstock

Task 2.5 Ocean Deployment and Scale-up

The goal of this task is to demonstrate that OMEGAs can function at sea and that they can be scaled-up using repeated modules.

A series of tests will be conducted over the 14-day growth cycle using OMEGAs moored in the ocean. These tests will include monitoring the stability of the OMEGAs themselves, their ability to grow algae at sea, and their effects on the surrounding environment. In addition to providing information about biology, engineering, and the environment, this task will determine what regulatory hurdles will confront the growth of algae in OMEGA and determine if this system could be permitted for deployment in the coastal waters off California.

The Recipient shall:

- Prepare Test Plan.
- Construct OMEGAs to be deployed at sea.
- Obtain permission or permits to deploy OMEGA arrays with secondary wastewater effluent and freshwater algae in Monterey Bay.
- Deploy arrays of OMEGAs that will be carefully monitored structural integrity, as well as for algae growth, lipid production inside the OMEGAs and the impact on the phytoplankton community outside the OMEGAs .
- Test filling and harvesting protocols at sea.
- Based on ocean deployment generate a design review and recommendations for OMEGA systems.

Products:

- Test Plan
- Precedent for using OMEGAs in California coastal waters
- Report of growth and lipid production at sea
- Information about impact of OMEGAs on marine ecosystem
- Critical Interim Progress Report for OMEGA feasibility

Task 3.1 Technology Transfer and Commercialization Activities

The goal of this task is to work with the NASA Technology Transfer Office to identify and form a relationship with an appropriate commercial or other entity, and transfer relevant technology to that entity. The technical team will be available on an as-needed basis to assist with commercialization activities.

NASA's missions are enhanced by expanding partnerships between NASA Directorates and nonaerospace U.S. industrial firms and by leveraging the venture capital community for innovative technology development. As appropriate for this project and its resulting research and technologies, NASA will seek partnerships with U.S. industrial firms and the venture capital community that support NASA's technology needs. Additionally, NASA invites industry and academia to review its strategic plans and contact NASA if there are opportunities for collaborative research or technology infusion.

The Recipient shall:

- Prepare a Technology Transfer Plan. The plan shall explain how the knowledge gained in this project will be made available to the public. The level of detail expected is least for research-related projects and highest for demonstration projects. Key elements from this report shall be included in the Final Report for this project.
- Conduct technology transfer activities in accordance with the Technology Transfer Plan. These activities shall be reported in the Monthly Progress Reports.

Products:

- Technology Transfer Plan (No Draft)